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The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms

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ABSTRACT

Technological interventions to address the problem of poor productivity of smallholder agricultural systems must be designed to target socially diverse and spatially heterogeneous farms and farming systems. This paper proposes a categorisation of household diversity based on a functional typology of livelihood strategies, and analyses the influence of such diversity on current soil fertility status and spatial variability on a sample of 250 randomly selected farms from six districts of Kenya and Uganda. In spite of the agro-ecological and socio-economic diversity observed across the region (e.g. 4 months year^{-1} of food self-sufficiency in Vihiga, Kenya vs. 10 in Tororo, Uganda) consistent patterns of variability were also observed. For example, all the households with less than 3 months year^{-1} of food self-sufficiency had a land:labour ratio (LLR) < 1, and all those with LLR > 1 produced enough food to cover their diet for at least 5 months. Households with LLR < 1 were also those who generated more than 50% of their total income outside the farm. Dependence on off/non-farm income was one of the main factors associated with household diversity. Based on indicators of resource endowment and income strategies and using principal component analysis, farmers' rankings and cluster analysis the 250 households surveyed were grouped into five farm types: (1) Farms that rely mainly on permanent off-farm employment (from 10 to 28% of the farmers interviewed, according to site); (2) larger, wealthier farms growing cash crops (8–20%); (3) medium resource endowment, food self-sufficient farms (20–38%); (4) medium to low resource endowment relying partly on non-farm activities (18–30%); and (5) poor households with family members employed locally as agricultural labourers by wealthier farmers (13–25%). Due to differential soil management over long periods of time, and to ample diversity in resource endowments (land, livestock, labour) and access to cash, the five farm types exhibited different soil carbon and nutrient stocks (e.g. Type 2 farms had average C, N, P and K stocks that were 2–3 times larger than for Types 4 or 5). In general, soil spatial variability was larger in farms (and sites) with poorer soils and smaller in farms owning livestock. The five farm types identified may be seen as domains to target technological innovations and/or development efforts.

1. Introduction

Smallholder farming systems in sub-Saharan Africa occur within diverse biophysical and socio-economic environments. Rural families develop different livelihood strategies driven by opportunities and constraints encountered in such environments. Agroecology, markets and local cultures determine different land use patterns and agricultural management practices across regions. Within localities and villages, households differ in resource endowment, production orientation and objectives, ethnicity, education, past experience and management skills (Crowley and Carter, 2000) and in their attitudes towards risks (e.g. Salasya, 2005), all of which shapes a diversity of natural resource management strategies. Recognising variability within and among farms and across localities is the first step in the design of policies to help

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poor farmers (Ruben and Pender, 2004), and a key one with regard to the adoptability and performance of new technologies proposed to improve agricultural production. Improved understanding of the main drivers of household diversity, and ability to categorise patterns of diversity that bear a relationship with livelihood strategies and farming objectives, should help to better target agricultural innovation.

In many regions of sub-Saharan Africa, smallholder farms exhibit a large degree of soil heterogeneity, which is the consequence of the inherent soil-landscape variability plus the effect of past and current land management (e.g. Garin et al., 1990; Prudencio, 1993; Carter and Murwira, 1995). The status and variability soil fertility within smallholder farms are likely to vary between households of different social status, cattle owners vs. non-cattle owners, or between those pursuing different long-term objectives (e.g. market orientation vs. subsistence). At the scale of individual farms, resource limitation forces farmers to preferentially allocate the available labour and nutrient resources to certain fields, which contributes to the creation of spatial soil variability (Tittonell et al., 2005b). This adds a new dimension to the 'niches' to which innovations must be targeted (i.e. the socio-ecological niches – Ojiem et al., 2006), since the performance of technologies may also be highly variable within spatially heterogeneous farms.

In the region of study, comprising the densely populated highland and midland humid zones of East Africa, wide variability in the regional drivers of agricultural systems have resulted in different land uses that range from strongly market-oriented smallholder coffee, tea and dairy systems, through semi-commercial cereal/legume-based systems, to subsistence oriented systems based on starch crops (Braun et al., 1997). In general, continuous cropping with few or no nutrient inputs coupled with removal of crop residues from the fields has led to a general poor fertility status of the soils (Shepherd et al., 1996), and the impact of household resource endowment on farm (and specifically soil) management has been well documented (e.g. Crowley and Carter, 2000; Nkonya et al., 2005; Barrett et al., 2006). Earlier studies in the region also showed that rural livelihood strategies to cope with limited access to (land, labour, monetary) resources were not only restricted to alternative methods of farm management and/or choice of production activities; off- and non-farm opportunities provided alternative or complementary livelihood strategies (e.g. Tittonell et al., 2005a).

Household categorisation is thus not only necessary to target agricultural innovations, but also to understand how the specific objectives and endowments of different household types affect resource allocation leading to soil heterogeneity. Previous studies in East Africa used various criteria and methods to categorise households for specific purposes: e.g. soil fertility research (Carter, 1997), agroforestry interventions (Shepherd and Soule, 1998), econometric and/or policy analysis (Kruseman et al., 2006), etc. A common denominator in most household clustering exercises is the use of wealth or resource endowment indicators, which are also used when farmers classify themselves through participatory wealth rankings (e.g. Mango, 1999). While all these constitute examples of structural household typologies, functional typologies that consider also the dynamics of production orientations and livelihood strategies may improve the categorisation of households, depending on the objectives of the analysis (Mettrick, 1993).

Our objective was to develop a consistent typology of farms and rural households to help us understand and categorise the diversity of livelihood strategies among smallholder farmers in mid- to high-potential agricultural systems of the East African highlands. This should contribute to fine-tune targeting innovations to address the problem of poor soil fertility in these agriculturally relevant systems, in the context of the major investments in this field that are planned for Africa (cf. www.agra-alliance.org). To this aim, we tested the typology in terms of its capacity to distinguish patterns of soil fertility management and status among farm types. We analysed socio-economic and management data from a survey of households in Kenya and Uganda and from farmers' participatory self-ranking, clustered households into homogeneous, meaningful groups, and studied soil variability and nutrient stocks within each group. Although we recognise the limitations of once-in-time or cross-sectional (vs. longitudinal) household surveys, pragmatism often imposes these as the most common, logistically feasible method of baseline household characterisation.

2. Materials and methods

2.1. Selection of study sites and farms

Six study sites were selected using a hierarchical approach designed to include differences in agricultural potential and access to markets (Table 1), located in Meru South and Mbeere districts in Central Kenya, Vihiga and Siaya districts in Western Kenya, and Tororo and Mbale districts in Eastern Uganda. Rainfall distribution across the whole region is bimodal, characterised by a long and a short rainy season that allow two cropping seasons per year. The sites at Meru South, Vihiga and Mbale districts are located in areas considered to have the highest agricultural potential within the East African highlands, due to their inherently fertile soils and ample rainfall (Jaetzold and Schmidt, 1982; Wortmann and Eledu, 1999). Population densities are high in Vihiga and Meru South, consequently with small farm sizes. Both lack communal areas for livestock grazing and thus intensive, 'zero-grazing' livestock systems prevail. The population density in Mbale is about the highest in Uganda, due to migrations from the central parts of the country at the beginning of the 20th century. Coffee is extensively grown as a cash crop in Mbale and Meru South, where tea is also cultivated. The area under cash crops in Vihiga (tea), Siaya (cotton), Mbale (coffee) and Tororo (cotton, tobacco) has decreased during the past decades. Ox-ploughing is more commonly observed in Mbeere, Siaya and Tororo, due to the larger size of the fields.

Within each of the six study sites four different localities were selected (totalling 24) that correspond to different administrative units of the districts considered. GIS layers for soils, agro-ecological zones and sub-locations (Kenya) or parishes (Uganda) were overlaid for each district. Soils considered to be of little agricultural importance were discarded, and the four localities were selected randomly from all sub-locations (in Kenya) or parishes (in Uganda) present in the six districts. Within each locality 10 farms were selected within a 1200 m diameter radius using a Y-shaped sampling frame. The sampling frame was designed to include those characteristics considered to occur at random (e.g. elevation, parent material, climate, landscape position) and 'fixed effects' considered under farmers' control (e.g. soil management, land use history). One farm was located at the centre of the 'Y' and three in each of the randomly oriented arms separated at constant distances from the central farm (at 100, 300 and 900 m). The 'Y' sampling frame was considered to be the most efficient way to avoid sampling bias while obtaining information on spatial correlation with fewest possible sampling points. Four Y-frames per district led to a final sample of 240 farms; an extra Y-frame was sampled in a fifth locality at Vihiga to include a previous benchmark site where research on soil fertility issues had been conducted, giving a total of 250 farms. The Y-frames were prepared using ARC–GIS software to obtain the exact geographical location of each farm. Farms were georeferenced using a global positioning system (GPS) device. Further details are described in Tittonell (2007).

Table 1
Main characteristics of the selected sites[a] in three sub-regions of East Africa.

Characteristic	Central Kenya		Western Kenya		Eastern Uganda	
	Meru South	Mbeere	Vihiga	Siaya	Tororo	Mbale
Site selection criteria						
Access to major markets	Relatively good	Relatively good	Intermediate	Intermediate	Relatively poor	Relatively poor
Agricultural potential	Relatively good	Relatively poor	Relatively good	Relatively poor	Relatively poor	Relatively good
Biophysical						
Altitude (masl)	1500	1100	1600	1200	1100	1600
Annual rainfall (mm)[b]	1600	700	1800	1400	1100	1200
Dominant soil types (FAO)	Nitosols, Ferralsols	Lixisols, Arenosols	Nitosols, Ferralsols	Ferralsols, Acrisols	Acrisols, Vertisols	Ferralsols, Acrisols
Landscape	Strongly undulating, slopes up to 45%	Fairly flat to gently undulating, slopes <5%	Gently undulating, slopes 5–20%	Fairly flat, slopes <3%	Fairly flat, slopes <3%	Gently undulating, slopes up to 30%
Socio-economic						
Population density (km^{-2})	800	400	1000	350	250	350
Farm sizes (ha)	0.5–3	1–10	0.3–2	0.5–5	1–8	0.5–5
Distance to major urban areas[c]	Close	Close	Close to medium	Medium to far	Medium to far	Far
Production activities						
Major food crops	Maize, beans	Sorghum, cowpeas	Maize, beans	Maize, cassava	Cassava, sorghum	Bananas, beans
Major cash crops	Coffee, tea	Khat, groundnuts	Tea, coffee	Sugar cane, cotton	Cotton, tobacco	Coffee
Livestock system	Zero grazing dairy systems and cultivation of fodder crops; improved cattle	Free ranging local zebu (traction) and goats; night corralling	Tethered cattle grazing in compound fields, zero grazing	Free grazing and tethered local cattle, used for traction	Free grazing in communal grasslands; local zebu used for traction	Zero grazing of cattle (traction) and goats; donkey used for transport

[a] Although probably more ambiguous, the term 'site' was preferred over 'district' to designate the six study areas. The use of district would imply that the sites chosen are representative of the full range of variability for entire district, which is not necessarily the case.
[b] In all sites rainfall is distributed bi-modally (i.e. long and the short rains seasons).
[c] This takes into account not only the physical distance but also infrastructure for transport and communication.

2.2. Household surveying

The selected farms were surveyed during the first (long) rain season of 2003 (March–July). Survey questionnaires were designed to capture biophysical, socio-economic and managerial aspects of each farm and national teams trained to administer them. Socio-economic and farm management information included characteristics of the household head (name, age, gender and marital status) and family structure, labour availability, sources of income, a map of the farm, land use patterns, use of/access to agricultural inputs, food security, livestock system, links to nearby markets, and production orientation. The different fields of each farm were identified with the aid of a map drawn by the farmer and the centre and perimeter of each field geo-referenced by means of a GPS. The surface area of each field was determined with a differential GPS. Biophysical information was collected on a field-by-field basis and included field characteristics (e.g. slope, landscape position, flooding, erosion, hard-settings, rock/stone cover, etc.) and management (e.g. the practice of fallow, nutrient input use, soil conservation measures, farmer soil fertility assessment, etc.). During the short rains season, community meetings were organised and participatory wealth ranking and resource flow mapping were implemented to delineate wealth classes, identify livelihood strategies and categorise household diversity. Further details and part of the information collected that are not presented are reported elsewhere (Tittonell, 2007).

2.3. Farm typology

A functional typology of farms that has been developed for western Kenya (Tittonell et al., 2005a) was used as the conceptual basis for household categorisation (Table 2). Households were categorised considering resource endowment plus criteria representing orientation of production activities (market, self-consumption), main type of constraints to agricultural production (as determined by land:labour ratios and cash availability), position of the household in the 'farm developmental cycle' (Forbes, 1949; cited by Crowley, 1997) and main sources of income for the household. Principal component analysis (PCA) was used to identify non-correlated socio-economic indicators to use as proxies for the household categorisation criteria described in Table 2, and households were grouped into homogeneous classes using iterative non-hierarchical cluster analysis (CA) complemented with reclassification of cases lying in fuzzy areas 'by hand', after closer examination of socio-economic indicators for these particular cases. The PCA was conducted using the socio-economic data (previously log or square root transformed and/or standardised for comparable ranges) to identify proxy indicators for the main drivers of livelihood strategies across sites. The loadings of the first most relevant principal components were examined for their bearings with meaningful indicators of the farm typology criteria (cf. Table 2). The main candidate variables to be included in the PCA at region scale were:

Total area owned by the household (ha).
Total area farmed by the household (ha).
Total area with cash crops (ha).
Family size (# members living and eating in the household).
Family labour (# members working on the farm).
Family members working temporarily/permanently off-farm.
Age of the household head.
% of household income from off/non-farm activities.
Number of years perceiving off-farm income.
Production orientation (% production for the market).
Total number of livestock.

Table 2
Key elements of a functional typology for household categorisation applied in western Kenya by Tittonell et al. (2005a).

Farm type	Resource endowment[a] and production orientation	Main characteristics[b]
1	Predominantly high to medium resource endowment, mainly self-subsistence oriented	Variable age of the household head, small families, mostly constrained by land availability (lack of family labour compensated by hiring-in). Permanent sources of off-farm income (e.g. salary, pension, etc.)
2	High resource endowment, market-oriented	Older household head, numerous family (starting land subdivision), mostly constrained by labour (hired-in) due to large farm areas; cash crops and other farm produce are the main source of income
3	Medium resource endowment, self-subsistence and (low-input) market-oriented	Young to mid-aged household head, young families of variable size in expansion, mostly constrained by capital and sometimes labour, farm produce and marketable surpluses plus complementary non-farm enterprises
4	Predominantly low to medium resource endowment, self-subsistence oriented	Young to mid-aged household head, variable family size, constrained by availability of land and capital, deriving income from non-farm activities (e.g. ox-plough service, handicrafts)
5	Low resource endowment, self-subsistence oriented	Variable age of household head, variable family size, often women-headed farms constrained by land and capital, selling their labour locally for agricultural practices (thus becoming labour-constrained)

[a] Referring to assets representing wealth indicators (i.e. land size, livestock ownership, type of homestead, etc.).
[b] These refer to the family structure (age of the household head) in relation to the position of the household in the 'farm development cycle' (Crowley, 1997), to the main constraints to agricultural production faced by the household, and to the main source of income.

Number of local cattle.
Number of graded (improved breed) cattle.
Number of oxen and ox-ploughs.
Months of food self-sufficiency.

Combinations of variables such as land:labour ratios, cattle densities or the % of the area under cash crops or farmed were alternatively tried in various analysis, but discarded when the original variables had the same or larger loadings with the major PC's. Complementary variables such as gender or marital status of the household head were not included in the PCA but used as criteria to refine the clusters later on. Subsequently, PCA's were performed for each site independently to check for consistency and the scores of the PC's that explained most of the variance (>95% – Sharma, 1996) and had meaningful loadings were included in a non-hierarchical cluster analysis for a first approximation to cluster households at each site independently. The resulting clusters were subsequently refined reallocating observations falling within fuzzy boundaries between groups and limiting the number of groups to five. The clusters were interpreted in relation to the major criteria of Table 2, considering the average and dispersion of the main indicator variables within and between groups at each site independently, and a farm type was assigned to each cluster. To do this the frequency distribution of such indicators was studied for each site individually, and either farmer-derived thresholds or n-*quantiles* were chosen cut-off values in consultation with the local surveying teams to check the outcomes of the cluster analysis (e.g. while the distribution of farm sizes was extremely asymmetrical, the age of the household head was normally distributed and thus 3-quantiles could be used to represent the three stages in the farm developmental cycle). The indicators and thresholds derived from discussions with farmers were checked for consistency across sites and localities.

2.4. Soil fertility and its variability within farms

Within each field of each farm soil was sampled within a 5×5 m quadrat located to avoid sampling bias and under- or over-sampling of edge effects on small fields. Within each quadrat, soil was sampled at three points along the slope, at 0.5 m, centre, 2.5 m and 4.5 m from the edge of the quadrat. Soil samples were taken using a soil auger of 5.3 cm diameter at 0–20 depth (composite of three samples) and 20–50 cm depth (central location only). A total number of 2607 geo-referenced composite topsoil samples were taken from the 250 farms. These were air-dried, weighed and passed through a 2 mm sieve. Soil fines (<2 mm) were also weighed. Visible-near-infrared diffuse reflectance spectroscopy (0.35–2.5 μm) was used to characterize the air-dried samples, which were scanned in Duran glass Petri-dishes using a Field-SpecTM FR spectroradiometer using the optical setup described by Shepherd et al. (2003). A subset of 20% (n = 430) of the soil samples selected on the basis of a principal components model of the first derivative reflectance values were analysed for particle size distribution, pH, organic C, total N, extractable P and exchangeable bases using standard methods described by Shepherd and Walsh (2002). Soil properties were calibrated to the first derivative spectra using partial least squares regression implemented in The Unscrambler (Camo Inc.). The analytical procedures for calibration and validation of predicted soil properties were described by Shepherd et al. (2003).

2.5. Data analysis

Comparisons across sites and household categories in terms of socio-economic and land use and management indicators were done through calculation of descriptive statistics and analysis of variance, with the explanatory factors site and/or household category (or 'farm type') and their interaction. To analyse soil fertility status (*SFS*) at farm scale we aggregated soil properties measured on the various fields of a farm into farm-scale weighted averages by adjusting the predicted soil properties of each individual field according to the proportion of its area relative to total farm area, as follows:

$$SFS_{(X)} = \sum_{i=1}^{n} SF_{(X)i} \times (FA_i/TFA) \quad (1)$$

where, $SFS_{(X)}$, Soil fertility status at farm scale for nutrient X; $SF_{(X)i}$, Soil fertility status (i.e. stock, availability) as predicted from the spectral soil analysis for each field in the farm (1–n fields); FA_i, Area of each particular field (1–n fields) (ha); TFA, Total farm area (ha).

After having categorised households into farm types, the variability associated with differences in soil fertility indicators between fields within single farms was estimated according to the residual variance term in the generic statistical model:

$$C_{ijk} = W_i + F_{ij} + P_{ijk} \quad (2)$$

where, the value of the predictor of a certain soil property (C_{ijk}) is the result of the effects of farm type (W_i, i = 1 to number of farm types in the categorisation) and of each particular farm (F_{ij}, j = 1 to number of farms per site); the unexplained or residual variance term P_{ijk} (k = 1 to number of plots per farm) was used as an

estimator of variability due to soil heterogeneity within farms. This variance term was used to calculate the coefficient of variation (CV) for each farm and soil fertility indicator. All analysis and calculations were performed using GenStat Version 10.

3. Results

3.1. Socio-economic diversity between sites

3.1.1. Land, labour and food security

Some of the most common indicators of household wealth or resource endowment did not vary across the region. For example, the average size of the households and the total number of cattle owned did not differ significantly between sites, while the average number of family members working full time on the farm was significantly larger in Siaya (3.3 adults) than in other sites with closer access to off/non-farm labour opportunities such as those in Meru South (2.2) or Mbeere (2.3). Most of the farms surveyed (156 out of 250) had less than 1.35 ha, with a median of 1.29 ha and with an average of 1.66 ha (Fig. 1a). Farmers in the Ugandan sites of Tororo and Mbale districts often doubled the area they used for cropping by annexing (hiring, buying) other pieces of land scattered around the villages. Significant ($P < 0.05$) differences between sub-regions were observed for the land:labour ratio (LLR, in ha person^{-1}; i.e. the number of adults working on the farm over the area of land available per family), but not between sites within sub-regions (Fig. 1b). At individual farm scale (Fig. 1c) LLR showed wide variability within sites, illustrating the value of this indicator for household categorisation.

Small LLR's indicate land limitation, whereas large values may indicate labour limitation, particularly when land preparation is done by hand-hoeing. Food self-sufficiency, however, was achieved in households with LLR ranging widely, from 0.02 to almost 5. All the food-insufficient households (e.g. <3 months year^{-1}) had LLR values < 1 and all those with LLR > 1 produced enough food to cover their diet for at least 5 months (Fig. 1d). Households with LLR < 1 were also those generating more than 50% of their total income outside the farm (Fig. 1e). The relative number of households per district with LLR > 1 and their average LLR was: 11/40 in Meru South (LLR: 2.9), 14/40 in Mbeere (LLR: 2.2), 3/50 in Vihiga (LLR: 1.5), 7/40 in Siaya (LLR: 1.7), 20/40 in Tororo (LLR: 3.2) and 24/40 in Mbale (LLR: 2.7). The relationship between LLR and the number of livestock head per farm (Fig. 1f) was less clear and only weak trends were found at this scale of analysis.

Households in Tororo achieved almost 10 months year^{-1} of food self-sufficiency on average, compared with less than 4 month-year^{-1} in the densely populated localities of Vihiga. About 70% of the farmers were predominantly subsistence oriented in Vihiga, whereas 80% were market-oriented in Mbale (Table 3a). The proportion of the farm area cropped to cash crops was 27% in Meru South, 11% in Mbeere, 4.8% in Vihiga, 0.8% in Siaya, 4% in Tororo and 22% in Mbale. Interestingly, a larger number of months of food

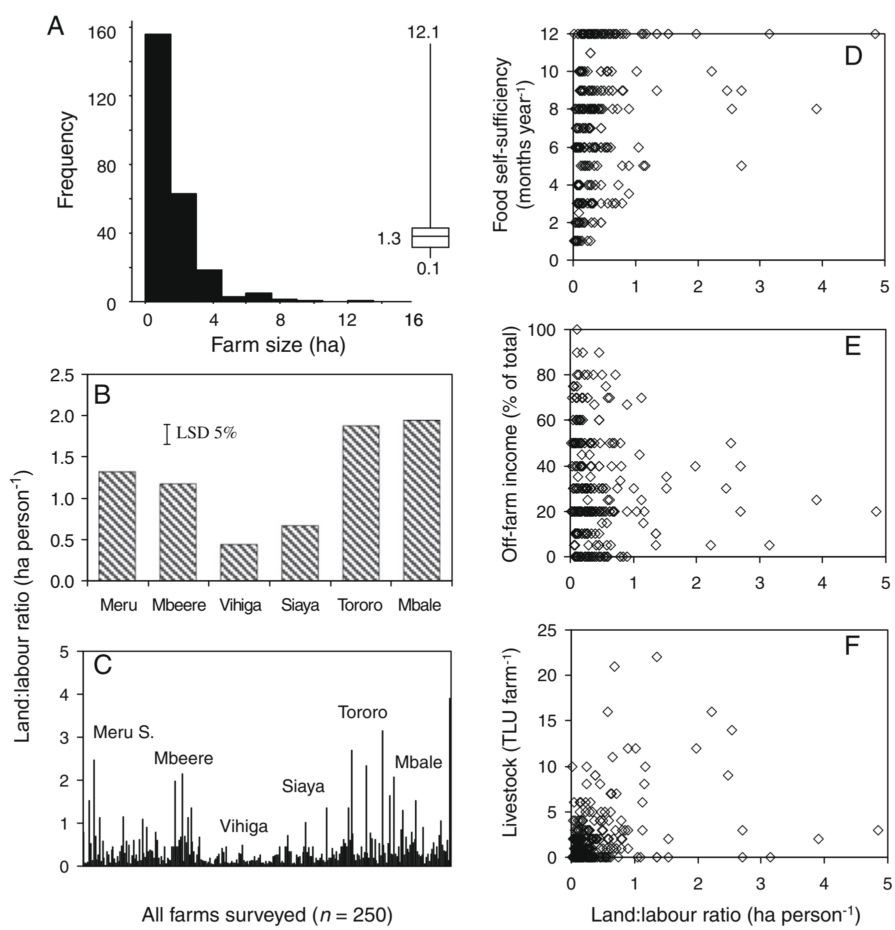

Fig. 1. Land, labour and socio-economic indicators. (A) Frequency distribution of farm sizes (inset: box-and-whisker plotting of farm sizes, indicating the median, close and extreme outliers, and figures indicating average, maximum and minimum values); (B and C) land:labour ratios per site (average) and per farm (n = 250), respectively; (D, E and F) the relationship between land:labour ratios and months of food self-sufficiency, percentage of off-farm income and livestock ownership, respectively. TLU: tropical livestock units.

self-sufficiency was achieved by predominantly market-oriented farmers. In Tororo, 45% of the households were food self-sufficient for 12 months a year, whereas in about 60% of the households interviewed in Vihiga all the food produced on the farm lasted less than 3 months (Table 3b). With the exception of Tororo and Meru South, households that achieved 12 months of food self-sufficiency owned almost twice the area of land, whereas households with less than 3 months of food sufficiency derived most of their income from off-farm activities, mainly working for other farmers.

3.1.2. Off- and non-farm income

Earning off-farm income represented an important livelihood strategy in all districts; the percentage of households having some kind of off/non-farm income varied from 60% in Mbale to 96% in Vihiga (Table 3c). Farmers in Vihiga estimated that almost 40% of the annual household income was generated by off- and non-farm activities, on average. In Meru South, closer to urban markets (cf. Table 1), more than 70% of the total income was generated by cash crops grown on the farm. Off/non-farm income sources ranged from remittances by members of the extended family living in cities, through petty trading or food aid to employment outside the farm. In most households in all districts at least one family member was temporarily or permanently working off-farm, and in about half of the cases family members were engaged in non-farm activities. Farmers sold their labour locally to other (wealthier) farmers to increase their family income (Table 3d) and, particularly in Meru South, their reason to do casual work outside their farms was, literally "because I am unemployed".

In line with these observations, the principal component analysis (PCA) done on the socio-economic data for the entire sample of farms ($n = 250$) indicated that roughly 80% of the household variability explained by the first two principal components (PC), which had respectively high positive and negative loadings with respect to the proportion of the total family income generated from off/non-farm activities and with the age of the household head (Fig. 2a–c). The third PC, more weakly associated with the commonly-used wealth indicators: total area farmed and number of livestock, explained virtually all the remaining variability; the

Table 3
Indicators of food self-sufficiency and livelihood strategies: (A) production orientations; (B) Indicators per class of food self-sufficiency, considering both extremes: less than 3 and 12 month year^{-1}; (C) income sources and labour allocation to off- and non-farm activities across sites; and (D) reasons given by farmers to decide on selling their family labour to other farmers as casual agricultural workers (e.g. for land preparation, weeding, livestock feeding, etc.).

District	Predominantly self-subsistence		Predominantly market-oriented	
	% of farms	Months of food self-sufficiency	% of farms	Months of food self-sufficiency
(A)				
Meru South	42	7.0	58	8.4
Mbeere	50	5.8	50	8.0
Vihiga	66	3.5	34	4.7
Siaya	48	6.9	52	7.9
Tororo	37	9.7	63	9.4
Mbale	20	9.0	80	8.1

Site	Frequency (%)		Farm size (ha)		Off-farm income (%)		Livestock owned	
	<3 months	12 months	<3 months	12 months	<3 months	12 months	<3 months	12 months
(B)								
Meru South	15	28	0.7	1.2	13	17	2.0	2.4
Mbeere	20	23	2.0	3.5	44	38	2.1	3.7
Vihiga	61	2	0.8	1.6	33	20	1.0	5.9
Siaya	5	5	0.5	1.2	20	21	0.0	6.1
Tororo	3	45	2.3	2.6	62	19	4.2	3.8
Mbale	8	24	0.8	2.9	50	9	1.3	4.9

Indicator	District					
	Meru S.	Mbeere	Vihiga	Siaya	Tororo	Mbale
(C)						
Proportion (%) of households that have some kind of off/non-farm income	90	93	96	88	88	60
Farmers' estimations of the % of total family income derived from off/non-farm activities	28	34	39	23	28	17
Proportion of households in which one or more family member						
Works temporarily or permanently off-farm	80	68	82	68	78	43
Is employed in non-farm activities	48	43	68	38	55	20
Sells his/her labour to other farmers	48	35	42	48	35	28

Reasons to decide on selling labour locally	% of farmers answering[a]	Districts with the higher frequencies for each of the answers
(D)		
Families who sell their labour		
"Because I am unemployed"	14	Meru S. (68%)
To increase family income[b]	64	Siaya (89%), Tororo (86%), Mbale (82%)
For necessity[c]	12	Mbeere (36%)
For need of cash income	9	Vihiga (43%)
Families who do not sell their labour		
Lack of time	63	Mbeere (96%), Siaya (86%), Vihiga (79%)
No need[d]	16	Tororo (42%), Mbale (24%)
Unable due to health condition	19	Mbale (41%), Meru (24%)
No or few opportunities, or badly paid	3	Tororo (12%)

[a] Out of 250 household interviewed, 98 families sold their labour and 152 did not; percentages were calculated on these values, respectively.
[b] In this case, income generated from farming and/or other income-generating activities was enough for subsistence.
[c] This answer implied that income generated by other activities, including farming, was insufficient for subsistence.
[d] No need due to enough income generated from farming and/or other non-farm activities.

contribution of the fourth and fifth PC's (family size, months of food self-sufficiency) explained only little of the remaining variation. While the % off/non-farm income is a general indicator of livelihood strategies, age of the household head indicates the position of the family in "the farm developmental cycle" and it is normally associated with resource endowment (households undergo a phase of expansion of their resource base from establishment to maturity – Crowley, 1997). Being orthogonal and thus independent, these two dimensions may be considered as starting points for a consistent categorisation of households across study sites.

3.2. Categorising household diversity

3.2.1. Farmers' criteria for self-categorisation

In participatory wealth ranking exercises farmers selected 'wealth' and 'farm management' indicators that were not always the same across districts and localities. Indicators such as food security, cash crops, livestock, labour and input use and timely crop management (closely associated with labour availability) were selected quite consistently by different groups of farmers, as illustrated for four localities in Western Kenya in Table 4. Land availability, income sources and commitment to farm work were alternatively selected in three of these four localities, whereas access to information, educational level, family size and the type of housing, among other broadly-used indicators, were less consistently selected. Therefore, the participatory categorisation of households based on these criteria was different for each of these localities: the proportion of households in the wealthier class varied from 5 to 13% across localities, but in the poorest class ranged from 30 to 80%. Although some of the criteria that farmers selected represent drivers of social diversity (e.g. availability of land and labour), others were simply a consequence of differences between households as induced by such drivers of diversity (e.g. timely weeding, use of hybrid seeds or veterinary services), and were highly correlated with each other. Yet, farmers' criteria and particularly the site-specific value of thresholds proposed for different indicators were highly valuable information to complement and refine the categorisation of households through formal clustering.

3.2.2. Farm typology

Households were grouped into five clusters considering main drivers of livelihood strategies represented by proxy indicators derived through PCA at each site independently. Table 5 shows the absolute value of the loadings (in %) of the major indicator

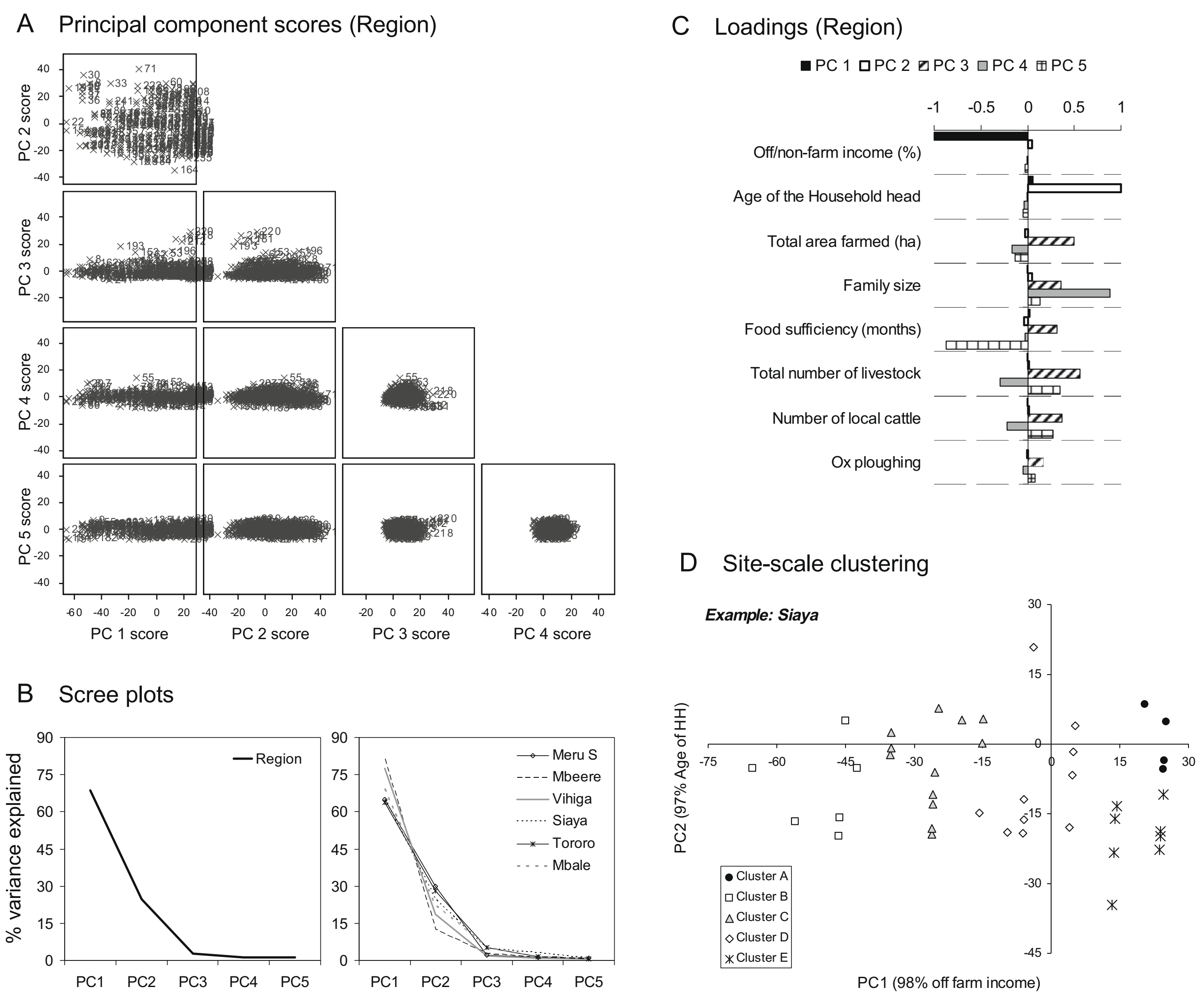

Fig. 2. Results of the principal component (PC) analysis done on the entire survey data ($n = 250$): (a) PC scores for each observation, (b) percentage of variance explained by each PC, (c) loadings of socio-economic variables included in the analysis with respect to the first five PC's, and (e) observations from Siaya district clustered with respect to the PC scores of a site scale PCA.

Table 4
Farmers' criteria to classify households in relation to resource endowment and farm management during participatory wealth rankings in Vihiga (Ebusiloli and Emusutswi) and Siaya (Nyabeda and Nyalugunga) districts, Western Kenya, and distribution of households within three wealth classes based on these indicators in the four localities.

Criteria	Key indicators/levels
Selected by farmers in the 4 localities	
1. Food security	Months of food self-sufficiency (8–12 Class I; 3–5 Class II; 0–2 Class III); having food surplus to market
2. Labour availability	Depending exclusively on family labour, complemented with hired labour or using exclusively hired labour
3. Cash crops	Presence and acreage of tea plantations (> or <1 acre); presence of tobacco, sugar cane, tomatoes; level of input use and maintenance
4. Livestock	Type and number of livestock heads owned (e.g. 3–5 improved dairy cows in Class I) and management system (stall fed, free grazing)
5. Use of fertilisers	Regular, occasional or no use of organic and/or mineral fertilisers; applied in most fields or only in homegardens; only basal or basal plus topdressing applications
6. Timing of farm operations	Timely planting and weeding, ownership/capacity to hire oxen for ploughing vs. hand-hoeing; labour hired for timely weeding
Selected by farmers in 3 of the 4 localities	
7. Land availability	Farm size (variable acreages across localities); hire-in, use own or hire-out land for cultivation
8. Use of quality seed	Use of certified seeds, maize hybrids; use certified in long rains and local seeds in the short rains
9. Income	Annual income (e.g. KSh 80,000–100,000; 30,000–50,000 or <10,000 for Class I, II and III, respectively, in Nyabeda); main source of income (on-farm vs. non/off-farm); permanent vs. intermittent off-farm income
10. Commitment to work	Hardworking vs. idlers; need to work for other farmers or commit to other occupations
11. Soil conservation	Presence and maintenance of permanent or semi-permanent (grass strips) soil conservation measures
Selected by farmers in 2 of the 4 localities	
12. Access to information	Having regular or sporadic access to agricultural information and knowledge, seeking extension services
13. Planting method	Planting in lines using oxen furrows or ropes vs. broadcasting
14. Weeding frequency	Weeding once or twice in the season or not at all, in all the fields vs. a few of them
Selected by farmers in only 1 of the 4 localities	
15. Type of house	Permanent brick houses vs. huts, tin roofing vs. thatched, maintenance
16. Transport means	Ownership/hiring wheelbarrow, bicycle, wheel carts
17. Veterinary services	Contracting veterinary services vs. using herbal treatments
18. Household nutrition	Number of meals a day (1, 2 or 3) throughout the year, balanced diets vs. starchy diets, meat consumption
19. Family size	Small families vs. large, polygamous families
20. Education level	Level of education (primary, secondary) completed plus additional training; well educated and informed
21. Postharvest storage	Presence of storage facilities (permanent) or use of drums, pots, sacks; use of chemicals vs. traditional methods for preservation

Locality	Class I	Class II	Class III
Relative proportion of households in each class[a]			
Ebusiloli	49 (10%)	277 (60%)	138 (30%)
Emusutswi	19 (5%)	58 (16%)	285 (79%)
Nyabeda	32 (13%)	125 (49%)	97 (38%)
Nyalugunga	29 (9%)	180 (53%)	132 (39%)

[a] Class I: wealthier households, good farm managers; Class II: moderately endowed, regular farm managers; Class III: poor households, poor farm management.

variables with respect to the first five PC's from the analyses done at each site individually. It is clear that the same pattern that was observed in the PCA at region scale (Fig. 2) was also observed at each individual site. Off-farm income, which particularly in Mbeere and Vihiga explained up to 80% of the variance (Fig. 2b), had the greatest loading with PC1 across all sites. PC2 was clearly dominated by the age of the household head, while PC3 was alternatively associated with the total area farmed, the size of the household or the number of livestock. In most cases, the first 3 PC's explained > 95% of the variance except in Siaya, where 4 PC's were needed. These PC's were used as classificatory variables in the cluster analysis, as illustrated for one of the sites in Fig. 2d. Partial correlations done on the data that were included in the PCA revealed that the age of the household head was mildly but positively correlated with indicators of resource endowment such as the ratio of livestock:land owned (r 0.26), family size (r 0.20),% of cash crops (r 0.15), members with a permanent off-farm income (r 0.14), months of food self-sufficiency (r 0.12) and number of improved cattle (r 0.11). The ratio of livestock:land owned was strongly correlated with the number of years receiving off-farm income (r 0.87).

Clusters were interpreted in relation to the five farm types identified earlier in the region (cf. Table 2). By examining the variability in the different indicator variables within each group we checked the membership of each observation to a certain farm type, and relocated those that did no comply with the criteria of the typology proposed. This is illustrated for one of the sites in Fig. 3, where the encircled observations are those that were relocated. For instance, the observation on the upper right hand side of the graph that was classified as Type 1, had actually most of the characteristics (in terms of resource endowment, family size, age of household head, etc.) of a farm Type 2. In this case, the household was not only well endowed in land and assets, producing cash crops for the market (cf. Table 2), but it also had an important source of off-farm income, at the same level of Type 1 farms. It is important to recall that the 'dependence' on off-farm income is a difficult variable to estimate without collecting accurate quantitative income data. The proxy variable used here was a (triangulated) estimation of what farmers' thought the importance of off-farm income sources was for their household. For the same reason, farmers who were typically land labourers (Type 5) were misclassified as Type 3, due to the small estimates of off-farm income they provided, or households with one or more members employed permanently off–farm (Type 1) were misclassified as Type 4.

Table 6 shows the average value of key socio-economic indicators for each farm type. Type 2 farms represent wealthier farmers owning relatively large farms, growing cash crops and keeping a larger number of livestock, who rely mostly on income generated by farming. Type 3 farms have similar income generation strategies but are less endowed in land and/or capital, and some family members may engage sporadically in off-farm activities to cover expenditure (e.g. school fees). Type 5 farms constitute the poorest category depending largely on off-farm earnings, in which often more than one household member is locally employed as a la-

Table 5
Absolute value of the loadings of the major classification variables with respect to the first 5 principal components derived at each site independently.

Site/variable	Loadings (%)				
	PC1	PC2	PC3	PC5	PC5
Meru South					
Off-farm income	93.2	35.6	0.7	2.1	5.3
Age of the household head	36.1	92.6	2.1	3.6	7.7
Total area farmed	0.5	4.5	38.1	53.1	53.5
Family size	2.0	6.5	18.1	47.3	82.4
Total number of livestock	0.9	9.1	14.8	52.1	12.2
Food self-sufficiency	1.6	0.4	88.5	42.1	9.1
Mbeere					
Off-farm income	99.8	3.4	0.2	2.9	1.8
Age of the household head	2.9	95.9	11.8	15.9	5.4
Total area farmed	2.8	14.7	30.9	85.6	7.1
Family size	1.6	15.7	0.8	16.8	33.8
Total number of livestock	0.9	2.4	55.6	4.1	54.1
Food self-sufficiency	0.5	12.3	72.9	29.0	51.6
Vihiga					
Off-farm income	99.9	0.2	1.5	0.3	1.3
Age of the household head	0.3	99.5	7.8	3.6	4.1
Total area farmed	0.3	0.6	10.0	10.9	6.4
Family size	1.1	9.2	89.5	37.4	10.1
Total number of livestock	0.9	1.9	12.7	14.5	48.4
Food self-sufficiency	0.6	0.4	34.8	88.3	5.8
Siaya					
Off-farm income	98.3	17.6	2.9	2.9	1.7
Age of the household head	17.3	97.6	11.7	1.9	1.8
Total area farmed	0.1	0.8	3.1	21.6	53.6
Family size	3.9	12.2	89.8	17.6	3.8
Total number of livestock	2.9	0.5	11.7	83.8	3.1
Food self-sufficiency	2.2	2.2	14.8	5.1	66.2
Tororo					
Off-farm income	96.8	24.1	1.1	0.6	0.1
Age of the household head	24.3	96.5	6.4	3.7	1.7
Total area farmed	0.7	6.3	51.9	69.8	29.7
Family size	1.2	0.6	10.6	38.7	74.1
Total number of livestock	1.9	2.5	78.1	45.2	6.1
Food self-sufficiency	4.2	6.8	0.6	9.9	40.0
Mbale					
Off-farm income	91.0	40.1	8.9	0.3	4.0
Age of the household head	41.3	89.4	16.9	1.7	1.2
Total area farmed	0.1	13.0	65.0	60.0	15.8
Family size	0.3	4.6	40.6	72.5	11.1
Total number of livestock	0.7	11.1	53.1	15.1	51.2
Food self-sufficiency	4.0	8.2	16.4	15.8	79.3

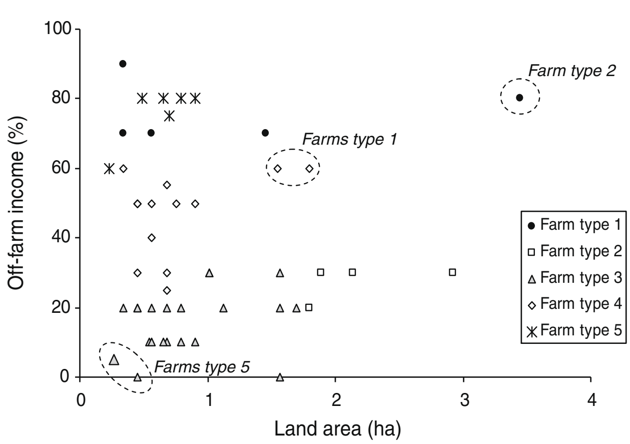

Fig. 3. Cases of misclassification when the categorisation of households was based solely on the cluster analysis done for Vihiga district. The five farm types identified from the clustering are plotted against their total area and their % of off-farm income. The encircled points are observations that were reclassified after analysis of the value of different indicator variables (see text for further explanation).

bourer by wealthier farmers. Type 1 represents a category of households that relies mostly on off/non-farm activities – as much as Type 5 – although such activities represent permanent employment and/or more-skilled jobs. Type 1 farmers are able to invest in sustaining or reproducing their resource base, and in achieving households needs (food security, education). Type 4 includes households with poor to medium resource endowment in which, next to farming, a varying range of off- and particularly non-farm strategies can be observed. Normally, they engage in activities which require less skill or are poorly remunerated (e.g. petty trading, providing oxen or transport services, manufacturing handicrafts, etc.).

Although the five strategies were identified across the six sites – albeit with different thresholds in the various indicators –, the distribution of households falling in each category varied between them (Table 6). This is due partly to the procedure for the sampling of households, but fundamentally to the regional variability of the main criteria used for stratification. For instance, the occurrence of farm Types 1 and 4 is determined by the characteristics of labour markets and the existence of non-farm opportunities at each site. Most livelihood indicators differed significantly across farm types within each district, with the notable exceptions of land available per family labour in Vihiga (where all categories were land-constrained, and where a significant interaction between district and farm type was observed) and months of food self-sufficiency in Tororo (where most farms were food secure). The % of off/non-farm income varied consistently within districts (the interaction district × farm type was not significant) but the average value varied considerably across districts (e.g. Vihiga compared with Mbale).

3.3. Variability in soil fertility and nutrient stocks at farm scale

A large portion of the variability in soil properties at farm scale was associated with the inherent geological and geo-morphological features of each site, as shown by the ranges of values for the weighted soil fertility status at farm scale (Eq. (1)) and its variability within the farm (CV), for different soil fertility indicators (Fig. 4). While the farms sampled in Meru South had the largest weighted average soil C varying within a narrow range between farms, those from Mbeere and Tororo had smaller average values and larger variability. Large inter-quartile variation in the weighted average P and K status was observed in Mbale, due to wider soil-landscape variability, while farms of Vihiga and Tororo had the smallest average values. Within individual farms, the largest relative variability was observed for available P, with extreme values for the coefficient of variation (up to 300% variability) between the different fields of individual farms in Vihiga and Siaya. Exchangeable K was also highly variable within farms, with CV > 1 in extreme cases. The CV of soil organic C between fields was in most cases < 0.3 and for soil pH < 0.1–0.2. Following the major biophysical gradients of the region, the average soil organic C and total N concentrations were greater in areas with finer-textured soils and higher rainfall (cf. Table 1); available P was higher in soils developed on the foot slopes of Mt. Kenya (Meru South) and Mt. Elgon (Mbale); the concentrations of exchangeable bases were higher in the heavier clayey soils of Siaya, while the highly weathered soils of Meru South and Vihiga had lower pH. On this biophysical background, the various farm types induced further spatial variability through strategic (preferential or constrained) allocation of carbon and nutrient resources.

Thus in general, the greater the weighted average value of a certain soil fertility indicator at farm scale, the smaller their variability within the farm (illustrated for C and P in Fig. 5a and c). Farms with 1 or 2 cattle exhibited more variability in soil fertility indicators such as soil C and available P than those without cattle or those with more than 2 cattle in Meru South, Mbeere and Vihiga

Table 6
Household categorisation and key socio-economic indicators for the five farm types across sites; distribution of households in each category, total land area and cattle ownership, land availability per family member and land:labour ratio[a], proportion of off/non-farm income perceived by the household and months of food self-sufficiency per year.

Site	Farm type	Distribution of households (%)	Total area owned (ha)	Owned cattle (TLU)	Land available (ha) per family[a]		Off/non-farm income (%)	Food self- sufficiency (months)
					Member	Labour		
Meru South	1	23	1.3	2.4	0.45	0.99	33	7.7
	2	13	4.0	5.6	1.13	3.40	16	9.4
	3	20	2.3	2.0	0.46	1.93	18	8.9
	4	20	0.8	1.4	0.23	0.44	36	5.8
	5	25	0.7	0.9	0.15	0.43	40	7.3
		SED (Farm Type)	*0.7*	*0.9*	*0.21*	*0.76*	*11*	*1.9*
Mbeere	1	28	1.7	2.1	0.46	1.33	46	7.1
	2	10	8.8	4.5	1.62	3.74	22	11.3
	3	25	1.9	2.7	0.36	0.75	17	6.9
	4	25	1.5	0.6	0.41	0.96	47	6.0
	5	13	1.1	0.4	0.31	0.48	61	5.6
		SED (Farm Type)	*0.7*	*1.9*	*0.23*	*0.49*	*12*	*1.6*
Vihiga	1	24	1.0	2.7	0.19	0.52	58	4.0
	2	8	2.0	5.4	0.30	0.69	30	7.6
	3	24	0.9	2.5	0.13	0.45	29	3.5
	4	26	0.5	1.8	0.11	0.39	42	3.2
	5	20	0.5	1.0	0.10	0.28	52	3.5
		SED (Farm Type)	*0.2*	*0.7*	*0.05*	*0.18*	*12*	*1.4*
Siaya	1	10	1.6	2.5	0.44	1.52	35	7.3
	2	13	3.2	7.2	0.59	1.10	12	8.6
	3	28	1.4	2.5	0.34	0.71	16	8.7
	4	30	1.0	1.0	0.20	0.41	26	7.2
	5	20	0.7	0.1	0.16	0.32	31	5.3
		SED (Farm Type)	*0.4*	*1.7*	*0.15*	*0.31*	*9*	*1.2*
Tororo	1	23	1.6	1.2	0.80	1.86	39	10.7
	2	20	4.1	9.5	1.19	4.33	11	10.4
	3	28	2.1	2.9	0.66	1.48	14	9.9
	4	18	1.4	0.9	0.26	0.73	27	8.1
	5	13	0.9	0.2	0.25	0.43	36	7.4
		SED (Farm Type)	*0.8*	*2.1*	*0.51*	*1.42*	*13*	*1.3*
Mbale	1	13	1.6	1.8	0.44	0.93	29	10.4
	2	15	3.6	9.0	1.67	4.74	9	11.0
	3	38	2.2	1.4	0.45	1.65	10	8.2
	4	20	0.9	0.8	0.37	1.68	33	7.5
	5	15	0.8	0.5	0.26	0.69	47	4.5
		SED (Farm Type)	*0.6*	*1.6*	*0.27*	*0.78*	*10*	*1.2*
		SED (Sites)	*0.4*	*0.6*	*0.33*	*0.11*	*5*	*0.6*
Significance (*P* values)								
Site (S)			<0.001	Ns	<0.001	<0.001	<0.001	<0.001
Farm type (FT)			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Interaction S × FT			<0.001	Ns	0.085	Ns	0.078	Ns

SED: Standard error of the differences; Ns: not significant.
[a] Calculated as land cropped over the total number of family members or the number of those working on the farm, respectively.

(Fig. 5b and d). These patterns were partly associated with the proportion of livestock-owning farmers that used manure at each site, 93% in Meru South, 80% in Mbeere, 96% in Vihiga, 63% in Siaya, 58% in Tororo and 53% in Mbale, with the proportion of them using mineral fertilisers: 95, 45, 80, 23, 5 and 0%, and with the average cattle densities observed: 2.1, 0.9, 3.3, 1.8, 1.7 and 1.4 TLU ha^{-1}, respectively. Due to unequal allocation of these nutrient resources in over time, the farm types differed more in the degree of variability within farm (the CV of the term P_{ijk} in Eq. (2)) than in the average status of soil fertility indicators ($SFS_{(X)}$ in Eq. (1)). For example, the widest amplitude of variation in soil C was observed for farms of Type 5 in Mbeere (CV: 0.46), while in Vihiga, Siaya and Tororo larger farms belonging to Type 2 exhibited wider variability of available P and K in their soils (0.85 and 0.57; 0.87 and 0.73; 0.99 and 0.44, respectively).

When the average stocks of C and nutrients in the soil were considered, wider differences were observed between farm types within each site (Fig. 6). The smaller C, N, P and K stocks for all farm categories were observed in Vihiga, as the result of both smaller farm sizes and poorer nutrient concentrations in the soil in most of the fields sampled. Large stocks of P were observed in Mbale, due partly to the inherent properties of the soils in the area, but specially to the large amounts of organic materials applied every year as mulches in banana fields (the main crop at this site – cf. Table 1). Farms of Type 2 exhibited larger C and nutrient stocks than the rest due partly to their larger size, followed by farms of Type 1, smaller in size but with greater cattle densities and access to cash income to buy fertilisers (cf. Table 6).

In the sites where mineral fertilisers were used, a proportion of 80–100% and of 74–95% of the farms of Types 1 and 2 used them, while only 12–35% of farms in the other categories. In Siaya and Tororo, mineral fertilisers were exclusively used by farms of Types 1 and 2 (data not shown). When the stock of nutrients on the farm was expressed as per family member or per family labour, significantly different stocks were observed between farm types (FT) and across all sites (S), without significant S × FT interactions (Table 7). While the poorest farm type in Meru South had an average *N* stock of *c.* 400 kg N family member^{-1}, the wealthiest farm type in Vihiga counted on *c.* 560 kg N family member^{-1}. Such differences were even wider for available P and K, and reflected the diversity in agri-

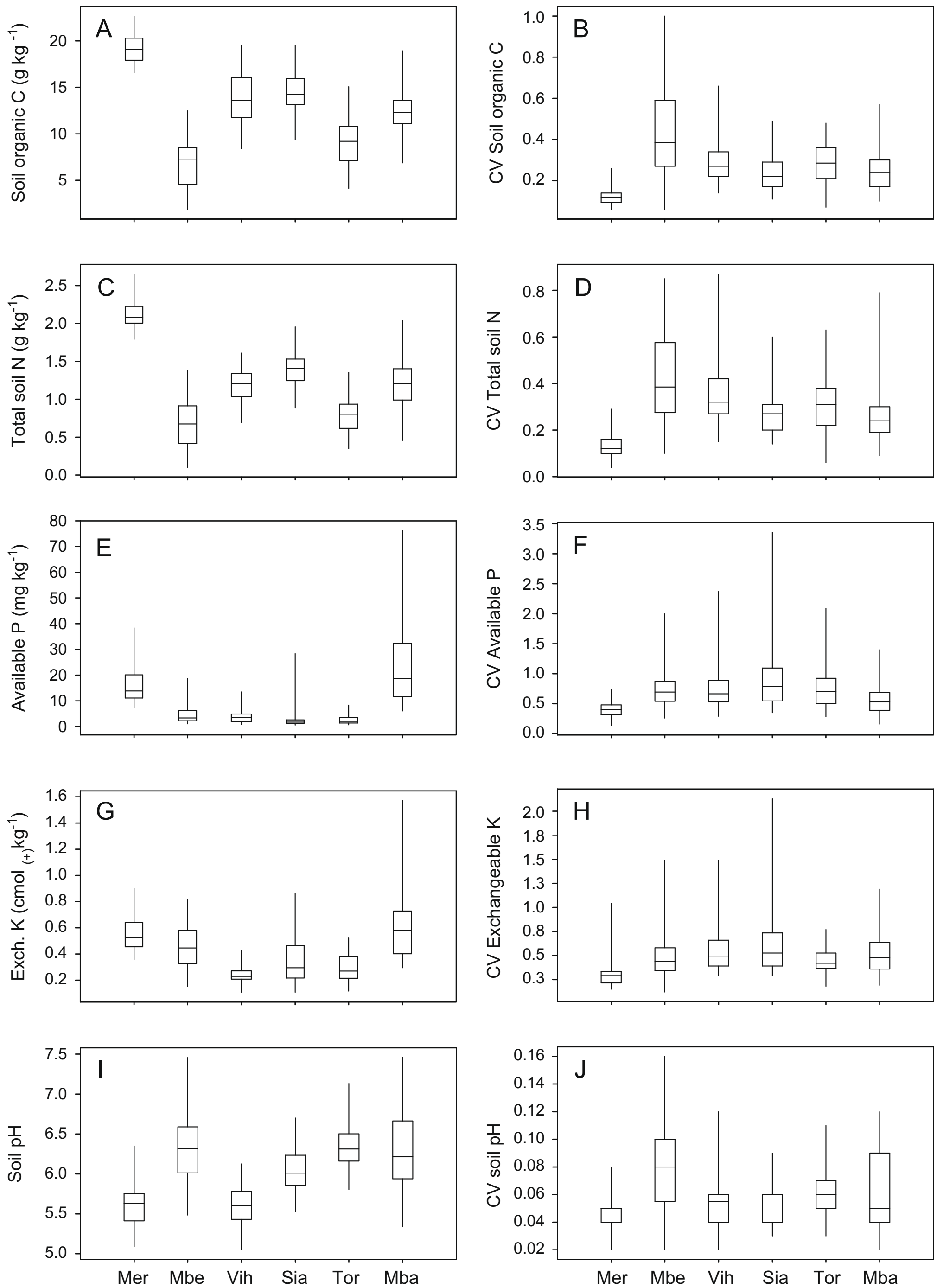

Fig. 4. Soil fertility status and its variability at farm scale across the six sites. The left panes are box-and whisker plots indicating the variation in farm-scale weighted average soil organic C, total N, available P and exchangeable K+ and pH; the right panes show the dispersion in the coefficient of variation of these indicators across the 250 farms sampled. Exch. K: exchangeable K; CV: coefficient of variation. Site abbreviations: Mer = Meru South, Mbe = Mbeere, Vih = Vihiga, Sia = Siaya, Tor = Tororo, Mba = Mbale.

cultural potential of the sites studied. In the sites where farms are larger and soil nutrient concentrations are low, such as Mbeere or Tororo, substantial investments in labour may be necessary to be able to 'harvest' the available nutrient stocks by cropping relatively large areas (cf. Table 6).

4. Discussion

Based on resource endowment, dependence on off-farm income and production objectives, smallholder farms in the highland and midland humid zones of East Africa were grouped into five farm types: (1) Farms that rely mainly on permanent off-farm employment; (2) larger, wealthier farms growing cash crops; (3) medium resource endowment, food self-sufficient farms; (4) medium to low resource endowment relying partly on non-farm activities; and (5) poor households with family members employed locally as agricultural labourers by wealthier farmers. These characteristics, however, pertain to the 'core concept' of each particular farm type. In reality, rural households may be highly dynamic and pursue various strategies simultaneously, sometimes only

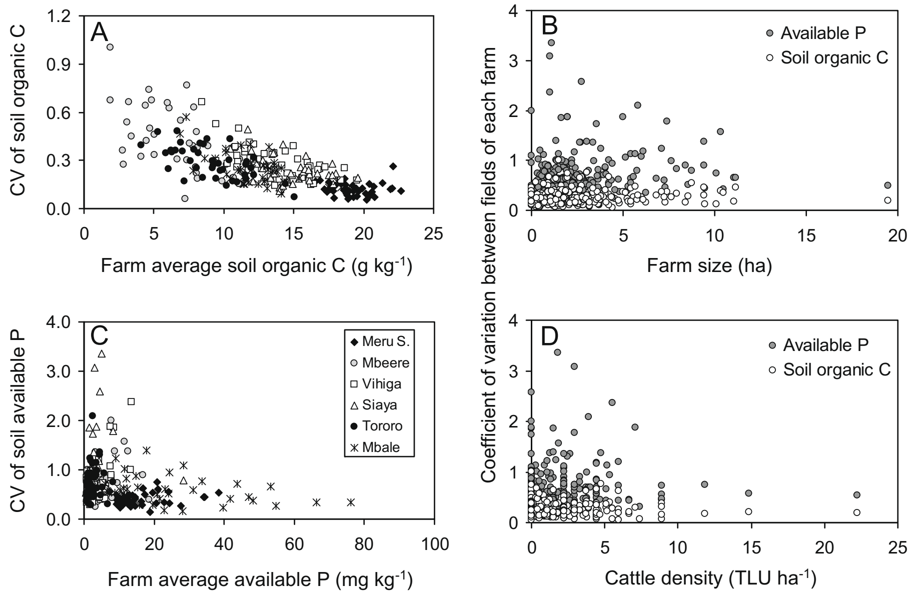

Fig. 5. The coefficient of variation of soil C and available P between the fields of individual farms (Eq. (2)) vs. their weighed average status at farm scale (Eq. (1)), for each of the sites. The coefficient of variation of soil C and available P as a function of (B) farm size and (D) the density of cattle population plotted for all sites pooled together. TLU: tropical livestock units.

for brief periods of time (e.g. Barrett et al., 2006). The proposed categorisation of households builds on from the most common structural typologies based on snapshot inventories of household resources and assets. This is illustrated in Fig. 7, where it is indicated that while farm Types 2, 3 and 5 had more clearly defined livelihood strategies, farm Types 1 and 4 showed wider variation in terms of resource endowment and income strategies, respectively. Market orientation increased from low or medium to high resource endowment farms, particularly for households generating most of their income by farming (Fig. 7b). Due to differential soil management over long periods of time, and to ample differences in resource endowment (land, livestock and labour) and access to

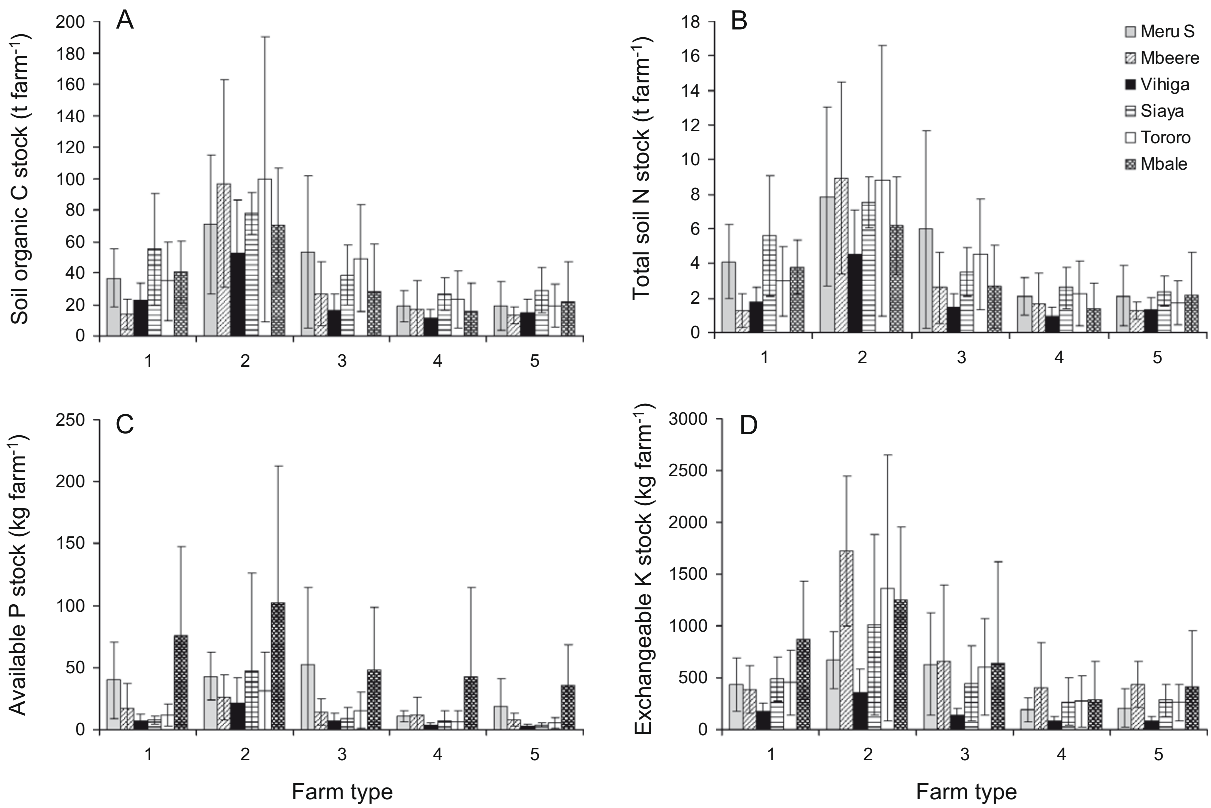

Fig. 6. Average soil stocks of organic carbon, total nitrogen, available P and exchangeable K at farm scale across different farm types in six districts of Kenya and Uganda. See text for a description of the farm types.

Table 7
Average farm-scale stocks of total N, extractable P and K expressed per family member (FM) and per family labor (FL) across farm types and districts.

Site	Farm type	N stock (kg person^{-1})		P stock (kg person^{-1})		K stock (kg person^{-1})	
		FM	FL	FM	FL	FM	FL
Meru South	1	802	1659	6.9	14.9	81	173
	2	1492	5838	8.2	29.4	132	463
	3	915	3420	7.8	32.1	97	359
	4	470	809	2.3	4.1	42	73
	5	403	1327	3.2	12.2	36	120
Mbeere	1	239	609	3.3	6.9	69	168
	2	1393	3134	4.7	8.4	275	628
	3	461	989	2.7	4.1	132	158
	4	444	947	2.4	5.2	99	228
	5	260	568	1.4	3.3	84	189
Vihiga	1	319	919	1.3	3.4	30	90
	2	558	1298	2.5	4.4	44	104
	3	171	659	0.8	2.6	17	61
	4	174	521	0.6	1.7	16	48
	5	258	693	0.5	1.4	15	47
Siaya	1	1232	3090	1.9	5.2	127	292
	2	1009	2329	6.5	12.1	143	281
	3	836	1822	1.8	2.9	126	209
	4	371	765	1.3	2.1	44	80
	5	375	846	0.5	1.3	40	100
Tororo	1	391	1555	1.6	5.5	66	228
	2	1080	3834	3.8	14.4	166	600
	3	863	1972	3.0	7.2	135	273
	4	384	1144	1.0	3.3	44	140
	5	262	552	0.8	1.8	41	88
Mbale	1	554	1716	10.9	15.6	123	329
	2	813	2346	11.2	42.5	134	448
	3	389	1642	6.9	31.3	86	463
	4	303	889	10.3	23.0	65	174
	5	500	1886	8.2	30.0	93	379
Significance (*P* value)							
Site (S)		0.001	0.001	0.001	0.001	0.001	0.001
Farm type (FT)	0.001	0.001	0.013	ns	0.001	0.006	
Interaction S × FT	ns	ns	ns	ns	ns	ns	
SED sites		121	414	1.1	4.9	23	81
SED farm type	112	378	1.1	4.5	21	75	
SED overall		275	935	2.6	11.0	52	184

cash, the five farm types exhibited important differences in their average soil C and nutrient stocks (cf. Fig. 6).

The differences in structure (endowments) and functioning (strategy) of these farm types may have implications for the design of technological innovations (Otsuka, 2000) and for the relative impact of changes in policy (e.g. Franzel, 1999). For example, farms categorised as Type 1 are not very dependent on agriculture, and probably less likely to benefit from outputs of agricultural

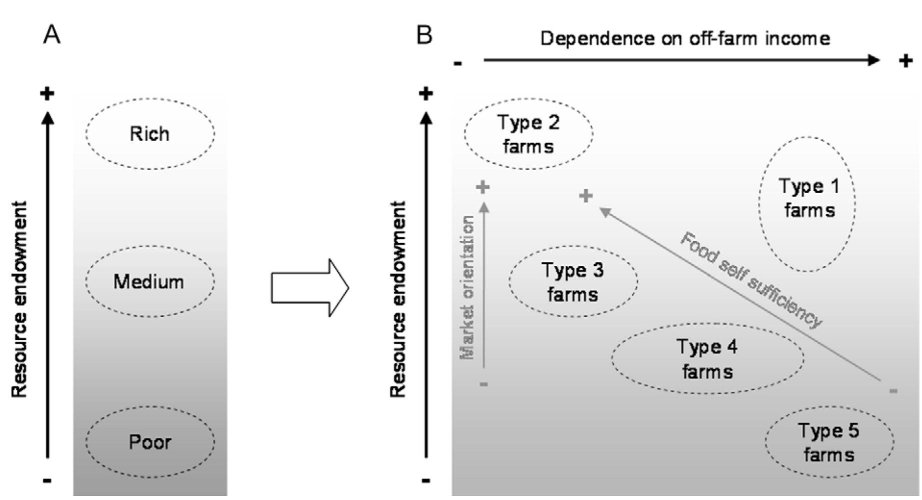

Fig. 7. The proposed farm typology, from (a) an approach based exclusively on the household's level of resource endowment to (b) a multidimensional approach considering the main source of income and production orientation. The intensity of shading roughly indicates of the distribution of households in a community. The farm types are encircled in dotted lines indicating that there are no actual clear-cuts between types but rather diffuse transitions between them.

research/development. They tend to operate as in semi-urban settings, where most of the family income is generated by permanent employment of the household head. Although their better financial situation may allow this type of farmer to invest in land, labour and/or agricultural inputs, other investments that represent strategic pathways out of poverty (e.g. higher education) are given priority (see similar examples in e.g. Andersson, 2001; Dorward et al., 2001). In farms of Type 5 multiple constraints in terms of resources, education and health – which had been often faced for more than one generation, limit the possibilities and motivation of these subsistence farmers to engage in technological innovation. This is often reflected in their lack of participation in agricultural extension activities (Misiko, 2007). Social security programmes designed to remove or alleviate permanent constraints faced by this type of household are a pre-requisite to allow them to implement technologies meant to improve agricultural productivity. Often, the on-farm income-based strategies pursued by farms of Types 2 and 3 means they are focused on increasing productivity, are often more innovative and their earlier adoption and adaptation of technologies may serve as example for other farmers within a certain locality. Although this hypothesis needs further testing (e.g. Misiko and Tittonell, 2009), examples in the literature indicate that this may facilitate the further dissemination of technologies within the community (e.g. Reij and Waters-Bayer, 2001).

Resource limitation may often induce a shift in livelihood strategies (e.g. Thornton et al., 2007), which in the cases analysed here manifests as a shift towards a higher dependence on off-farm income. This may have an effect on decision-making, farming practices and certainly on household priorities for investing cash and labour resources (Crowley and Carter, 2000). Engagement in off/non-farm activities was observed in a large number of the farms visited, to the extent that farmers in Meru South felt 'unemployed' when they spent their time on their own farms. Contradicting the principles of the farm developmental cycle, old household heads retired from non-farm jobs may still bring in an infusion of capital earned from years working off the farm or, due to the impact HIV/AIDS, old household heads may still manage large households. These strategies are more clearly exposed by functional rather than structural household typologies (Jouve, 1986). Independently, Brown et al. (2006) arrived at comparable household categories for Kenya using cluster analysis based on econometric variables, while Mbetid-Bessane et al. (2003) found comparable household categories in areas of central Africa, for systems that differ considerably in terms of farming and socio-cultural aspects. Cabrera et al. (2005) demonstrated the importance of considering household composition to identify rural livelihood strategies, and aspect that was not included quantitatively in our analysis. Farmers' self-categorisation through participatory wealth rankings, which is often practiced in agricultural research/extension (e.g. Baijukya et al., 2005), may help gaining insight in their goals, priorities and indicators of success. In our case, farmers consistently indicated food security and labour availability as main criteria for farm stratification. However, the causes (e.g. farm size, assets) and consequences (e.g. timely crop management, use of manure) of household diversity are often confounded in such exercises (cf. Table 4).

Across sites, the five farm types differed more in their degree of soil heterogeneity than in their average soil fertility status. This may be the result of different facts with potentially additive effects: (i) The spatial randomisation of the sampling of farms (the Y sampling frames) led to larger farms having a greater chance of being captured by the sampling grid. While this sampling allows good representation of the biophysical variability at landscape scale, it does not necessarily lead to a fair representation of the distribution of farms of different resource endowment. (ii) In heavily dissected landscapes such as those of Meru South, Vihiga or Mbale, small (poor) farms located on top of the ridges may even have better *average* soil properties than larger (wealthier) farms which cover both ridge and slope land. (iii) In the various sites analysed agriculture has been practiced for varying periods of time, with different intensities of land use, and soils have undergone different processes and degrees of degradation. This also applies to different farms sampled within a certain site. (iv) Better endowed farmers have access to larger amounts of organic carbon and nutrient resources (and labour) that can be more evenly distributed across their farms.

Studies across sub-Saharan Africa showed that differences in farmer-induced soil heterogeneity are largely due to the differential availability of nutrient resources, in particular manure, between farm types (e.g. Zingore et al., 2007; Samaké et al., 2006; Tittonell et al., 2005b). Animal manure is a key resource for nutrient management, and farmers create zones of soil fertility by preferential allocation of this resource – especially when it is in short supply. The interaction between the different agro-ecological potential across sites and resource endowment across farm types may be either aggravated or overrun by demography, resulting in different *current* potential for food production per capita with few external inputs. This is illustrated by the stocks of total N, available P and exchangeable K in the soil expressed per family member (cf. Table 7). The soil stocks of nutrients potentially available per family member are a pre-requisite to achieving food self-sufficiency; then, it is a question of how efficient is the production system (or what is the contribution of a certain technology) to capture and convert those nutrients into food or cash.

In spite of the diversity between sites and households described here, all the farms included in our study can be considered to be resource-poor smallholders, in agreement with the regional socio-economic variability reported as poverty maps for Kenya and Uganda (e.g. Thornton et al., 2006; Woldemariam and Mohammed, 2003; www.worldbank.org/research/povertymaps/). While the maps for Uganda indicate that 25–35% of the population in the sampled sites in Tororo and Mbale district are below the poverty line, the sites in Kenya correspond to areas where 40–50% (Meru South and parts of Vihiga), 50–70% (Vihiga and Siaya) and more than 70% (Mbeere and parts of Siaya) of the population are below the poverty line. Although for the purpose of targeting interventions we differentiate farmers that are relatively 'wealthier or poorer', the actual differences in resource endowment between these classes is generally narrow – indeed 60–70% of the households are below the poverty line. The observed values for socio-economic indicators were also within the range of those presented in population surveys (e.g. IEA, 2002 – www.ieakenya.or.ke; MFPED, 2001 – www.popsec.or.ug). Unfortunately, and beyond notable exceptions (e.g. Pender et al., 2006), most of the results from the large number of projects that have conducted farm surveys in the region are not easily accessible for comparison.

5. Conclusions

The five farm types identified in these agriculturally relevant areas of East Africa differed in land, labour and financial resources and potential nutrient availability (e.g. animal manure), all of which has an influence on agricultural productivity and soil fertility management. This typology of households distinguished farms that differed in fertiliser use intensity, hence in management-induced soil variability, and in total carbon and nutrient stocks per farm and per family member. More variability in soil fertility was observed within farms with generally poorer soils, and less in farms owning livestock. The proportion of households falling within each category may be expected to vary for different sites and this has implications for the design of strategies for poverty alleviation. In up to 80% of all households interviewed in a certain loca-

tion at least one member of the family worked temporarily or permanently outside their farm. Such dependence on off-farm income may be indicative of households that are stepping out of agriculture as a means of subsistence and/or income generation – a natural response to increasing population pressure on the natural resource base. The typology of rural household proposed here, which may be generalised consistently across the diversity of sites studied, may contribute to better targeting innovations. While households that exhibit a more agriculture-based livelihood strategy are more likely to implement and eventually adopt proposed technologies for agricultural intensification, farmers in the poorer categories should be the major beneficiaries of social promotion (policy/development) interventions. Bearing in mind the latest recommendations by the World Bank, and in the light of our findings, only the better endowed farmers are likely to benefit form the promotion of agriculture as the principal engine of rural development in these areas of East Africa.

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